Garbage Dump in the Sky

Space Debris and its Impact

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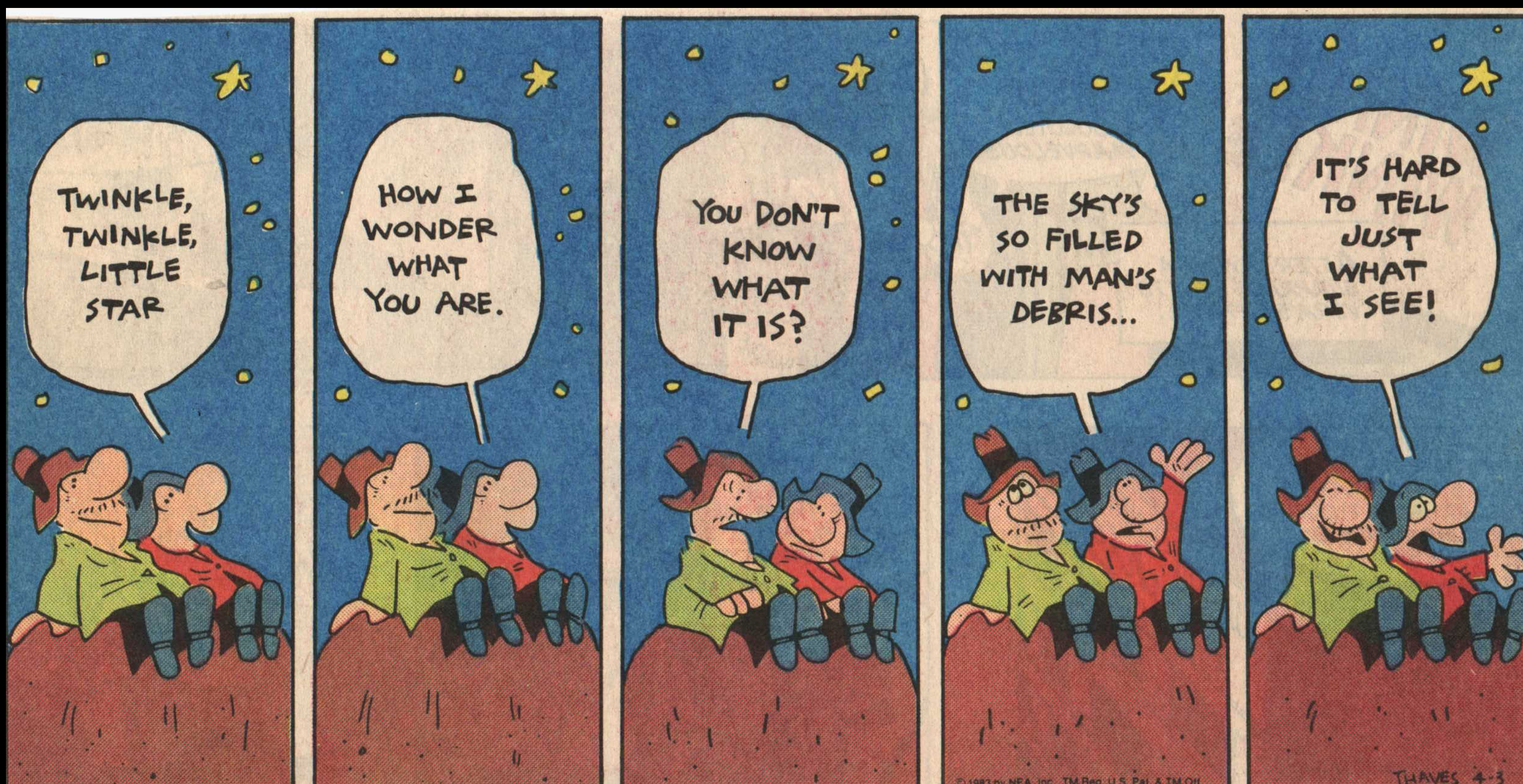

TWINKLE, TWINKLE, LITTLE STAR
HOW I WONDER WHAT YOU ARE.
YOU DON'T KNOW WHAT IT IS?
THE SKY'S SO FILLED WITH MAN'S DEBRIS...
IT'S HARD TO TELL JUST WHAT I SEE!
THAVES 4-3

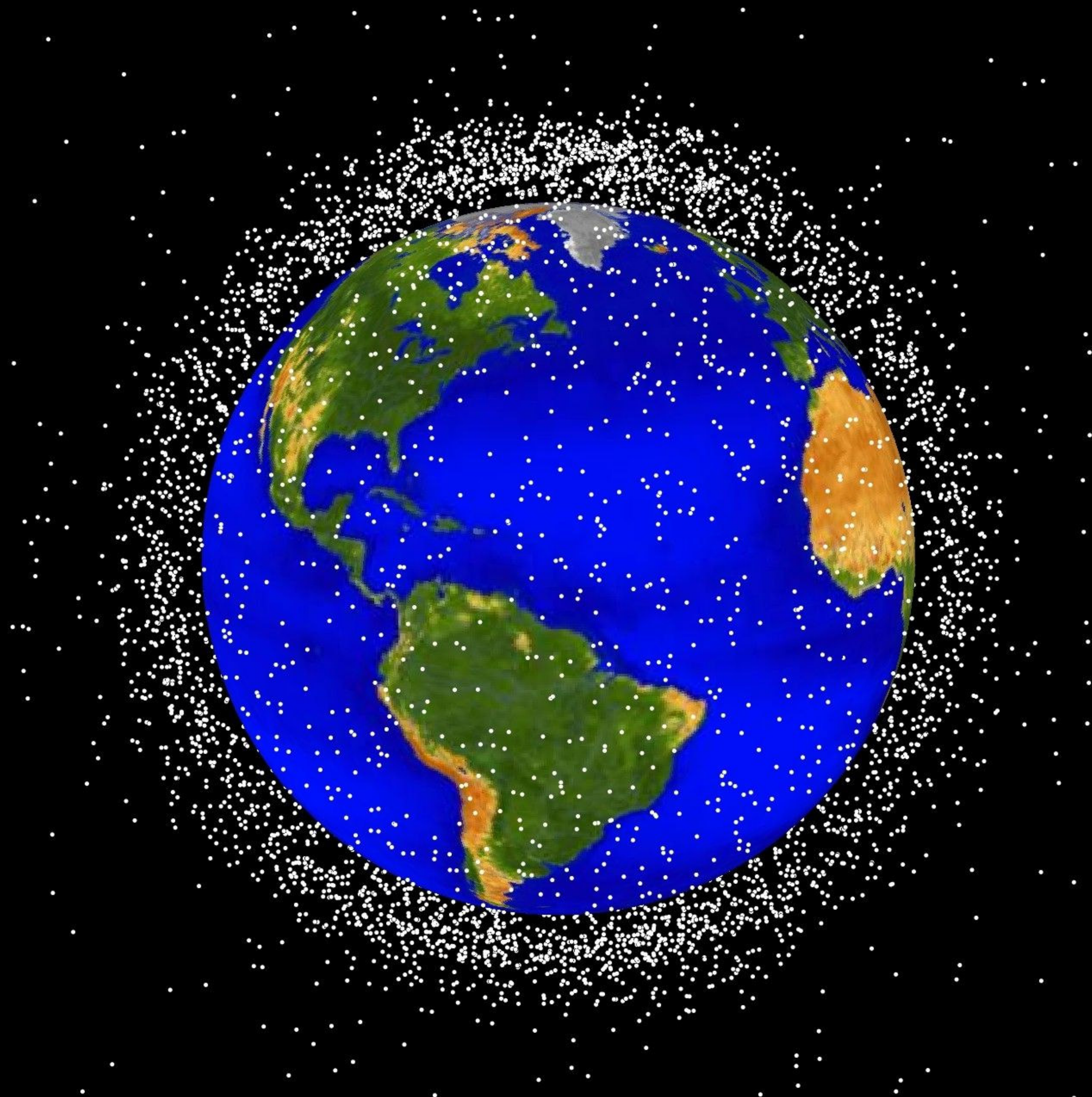
A Few Definitions

- Low Earth Orbit (LEO): Orbits with altitudes up to 2000 km.
- Middle Earth Orbit (MEO): Orbits between 8000 and 20,000 km.
- Geostationary Orbit (GEO): Orbits at altitude of 35,786 km (period is 24 hours, so satellite remains fixed above rotating Earth).
- Catalog – a collection of orbital elements for tracked bodies in orbit.

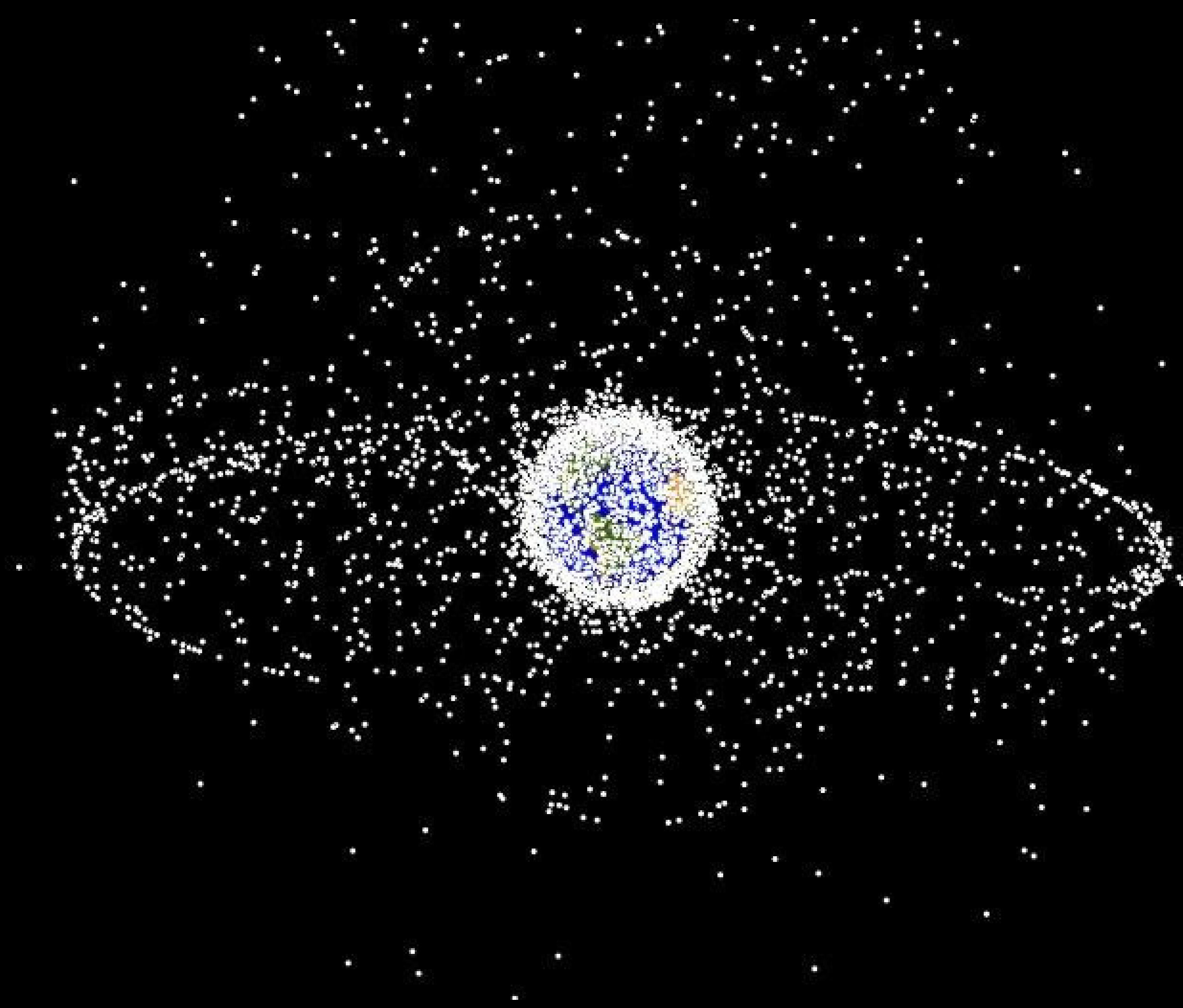
The On-Orbit Population

- Many thousands of trackable (>10 cm) objects – active and inactive satellites, rocket bodies, and debris of various sorts.
- About 5% of objects in the catalog are satellites (on average) – Percentage is higher under 600 km altitude because drag decays orbits of debris and inert satellites fairly quickly.
- Distribution of objects is **<u>not</u>** uniform with altitude and inclination.

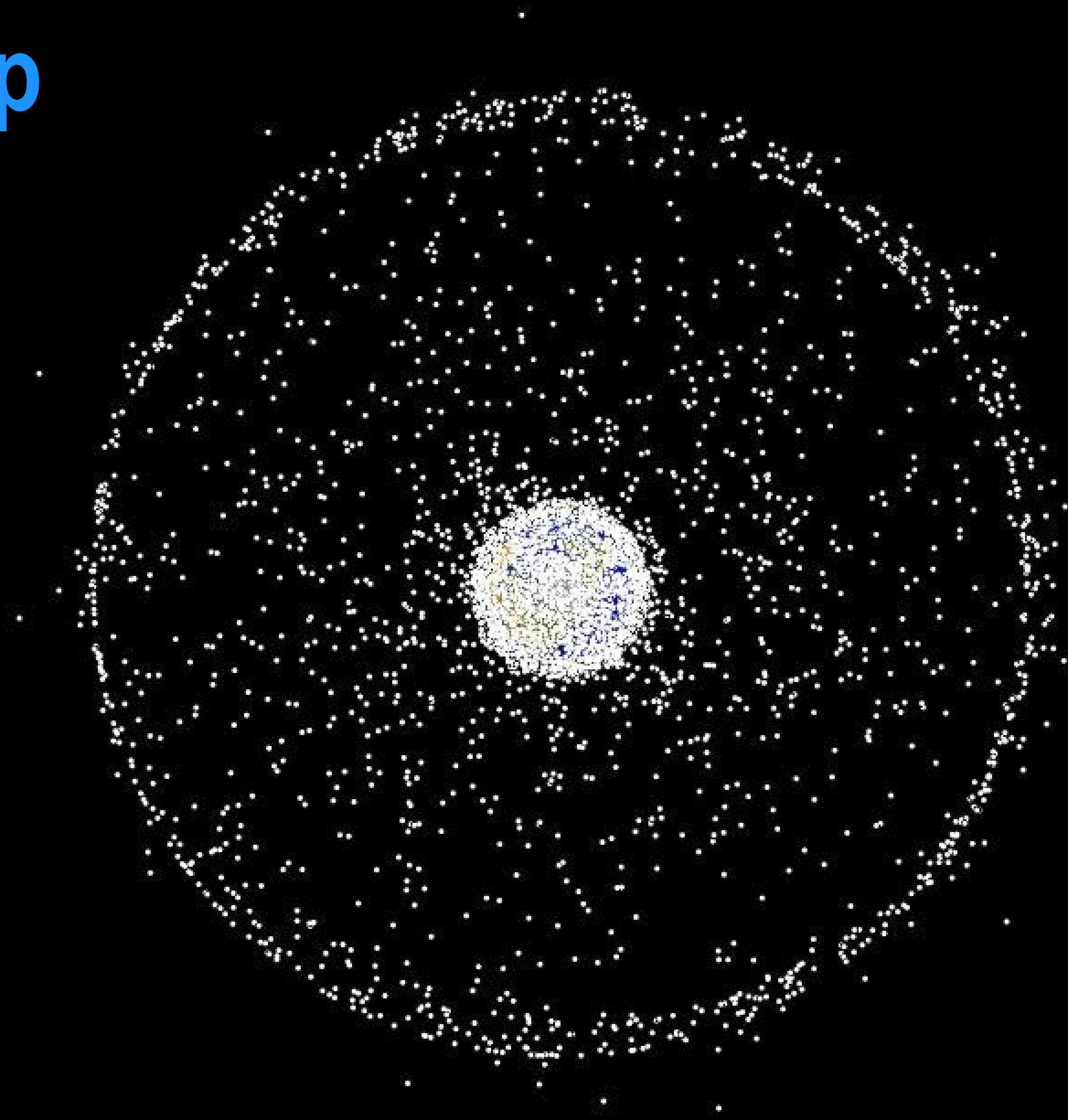
LEO View



GEO View



From the Top

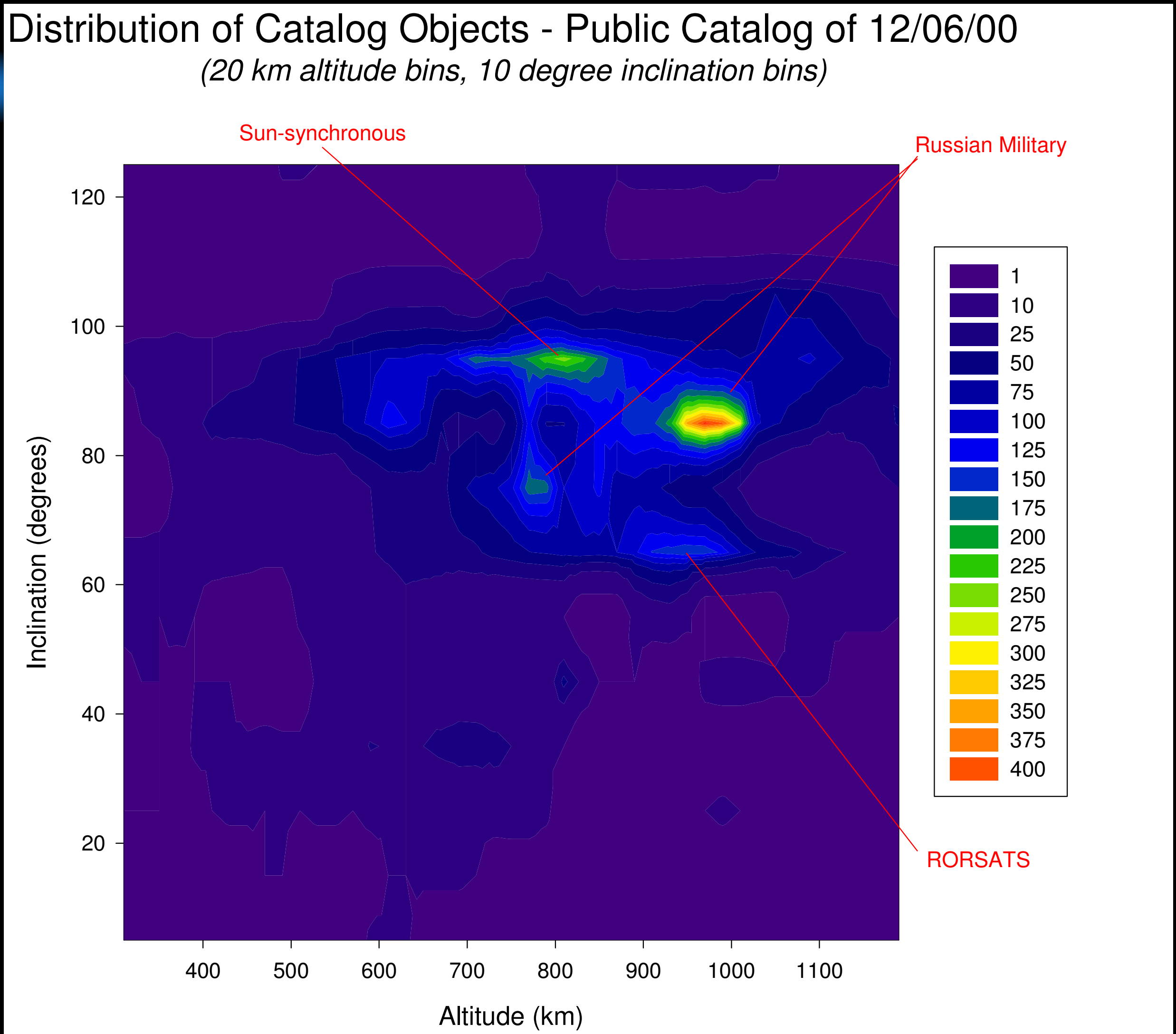


How much?

- The previous few slides were for the objects we can track – stuff > 4” (10 cm) in diameter (Catalog is 95% complete at this level). About 10,000 of these.
- There are many more objects we don’t track – reliable estimates (based on observations) place the number of particles with diameters between 1 and 10 cm at over 110,000.
- The same math estimates that there are over **35 million** debris particles smaller than 1 cm in Earth orbit.

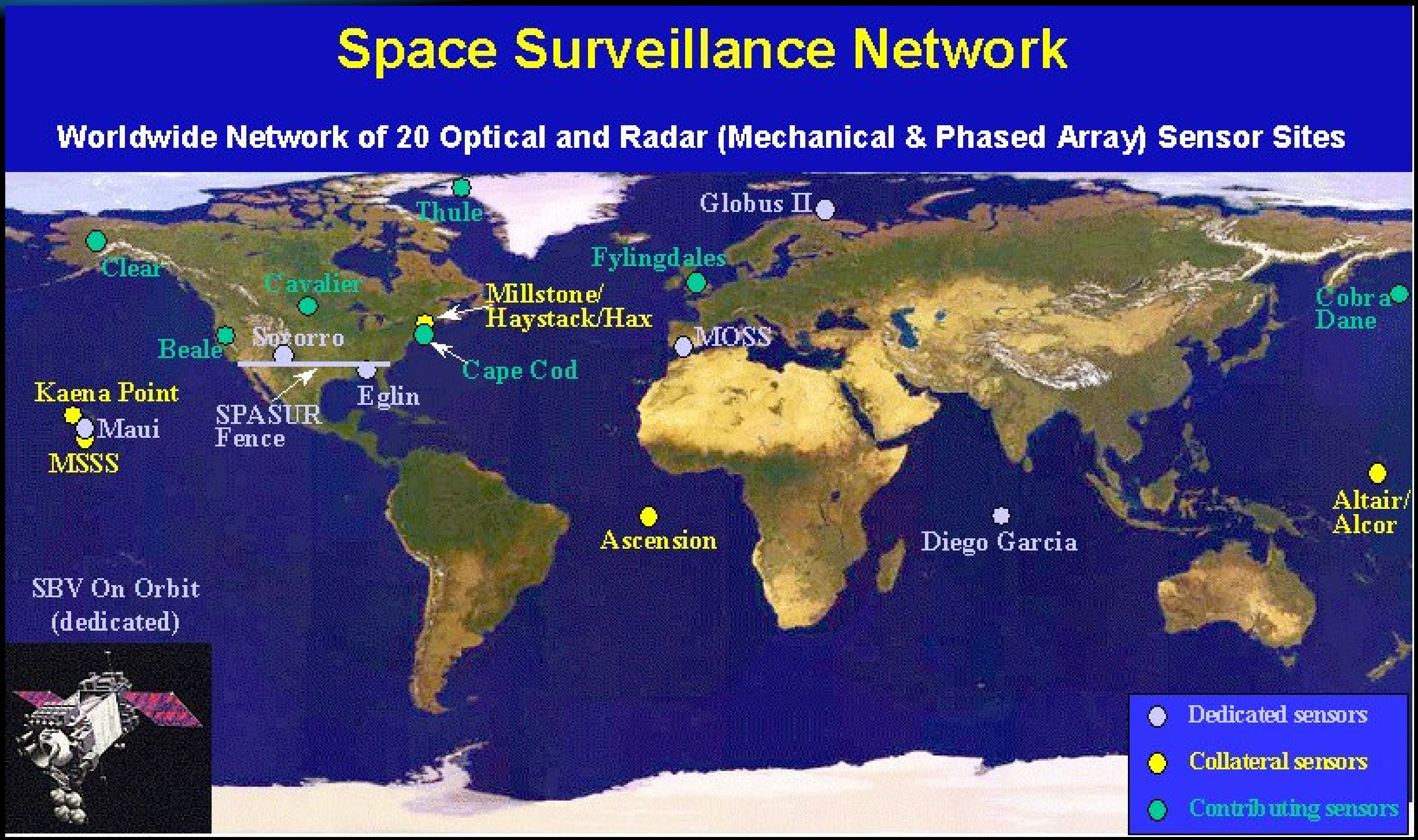
Atmospheric Drag Is Our Friend…

- Drag keeps <550 km altitudes fairly clean; altitudes between 700 and 1100 km densely populated for inclinations >60 degrees.



Keeping Track

- The Space Surveillance Network is a global suite of radar and optical sensors (plus MSX), operated by DoD (US Air Force STRATCOM).
- Designed for tracking incoming missiles.
- Effective size limit for tracking is 10 cm; some sensors can track down to 5.
- Data is sent to command/analysis center at Cheyenne Mountain, Colorado.

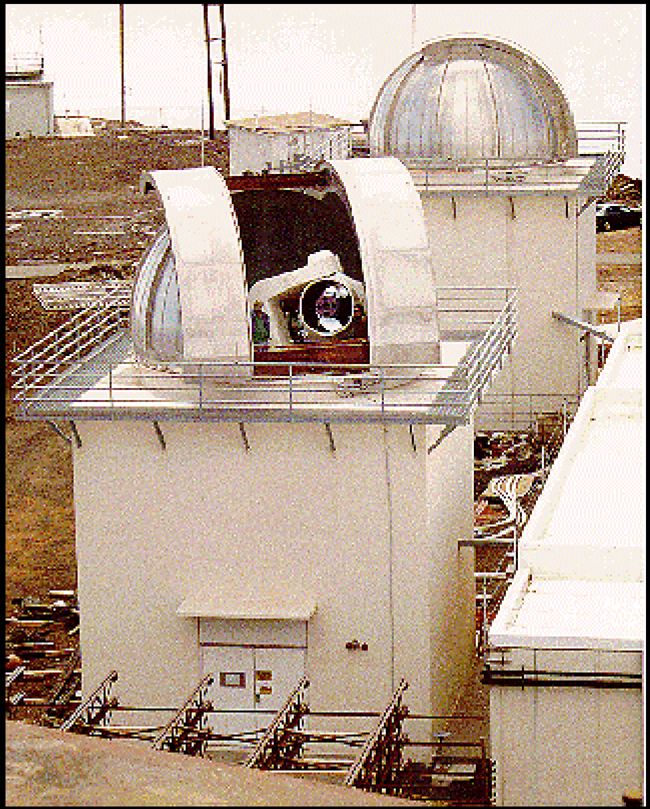

Space Surveillance Network
Worldwide Network of 20 Optical and Radar (Mechanical & Phased Array) Sensor Sites
Thule
Globus II
Clear
Fylingdales
Cavalier
Millstone/
Haystack/Hax
Cobra
Dane
Beale
Socorro
MOSS
Cape Cod
Kaena Point
Eglin
SPASUR
Fence
Maui
MSSS
Altair/
Alcor
Ascension
Diego Garcia
SBV On Orbit
(dedicated)
Dedicated sensors
Collateral sensors
Contributing sensors

Sensors of the SSN

Haystack (r) and Haystack Auxiliary (l) Radars

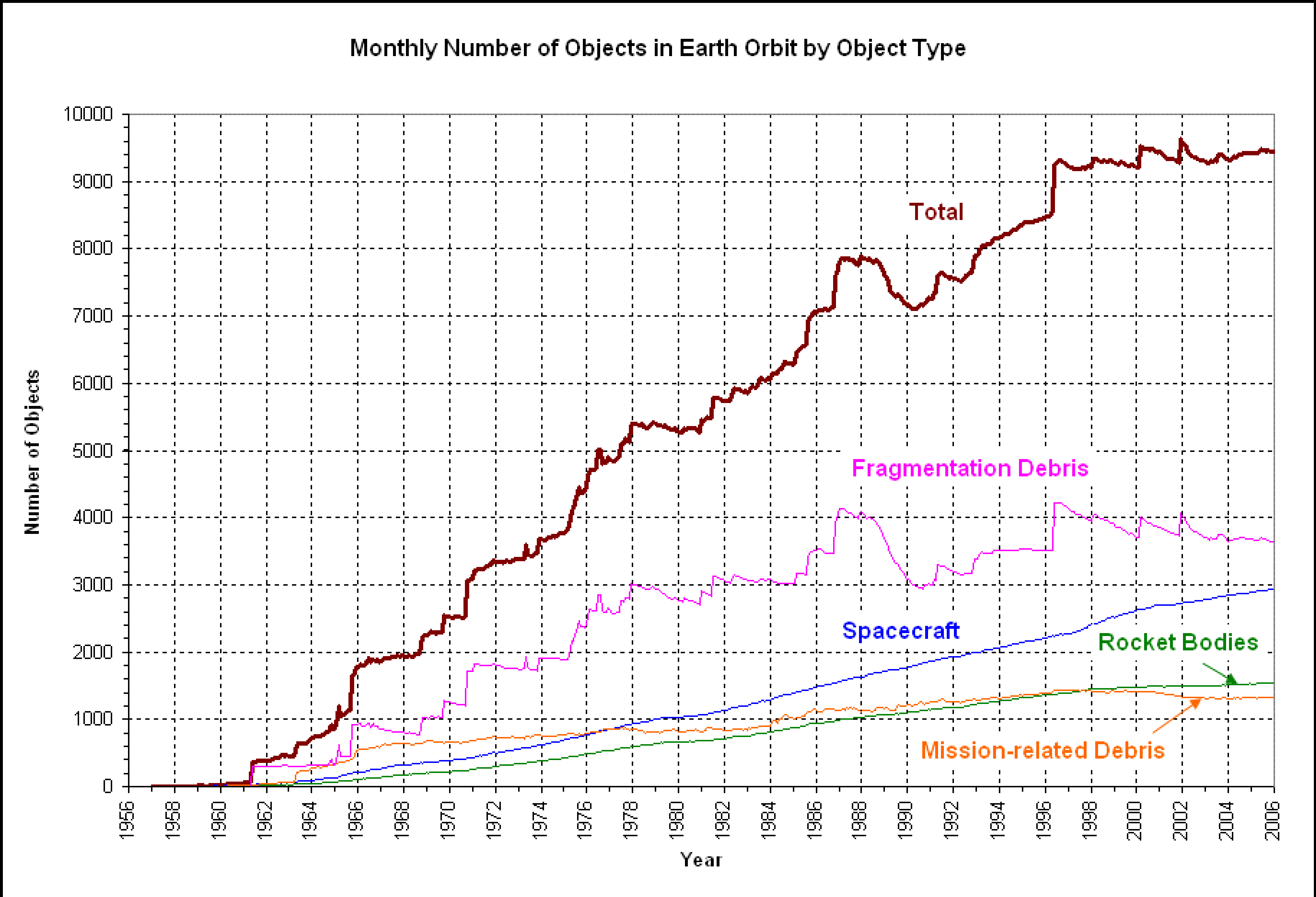
US Army ALTAIR Radar

Ground-based ElectroOptical Deep Space Surveillance (GEODSS)



Types of Debris

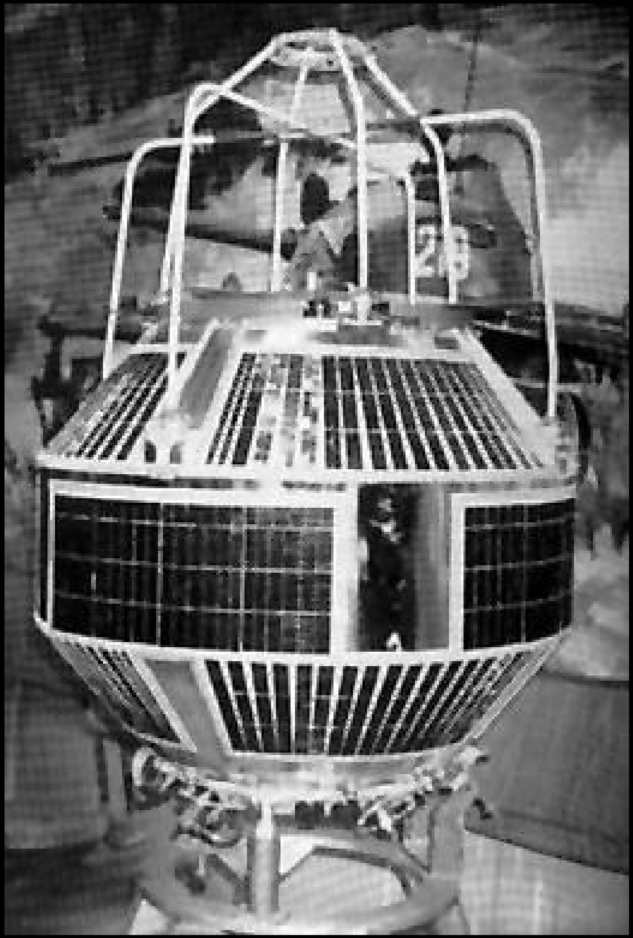
- Satellites.
- Rocket bodies – used upper stages (hopefully empty).
- Mission-related debris – payload/instrument covers, shrouds, gloves, tools, etc.
- Fragmentation debris – remnants of explosions.



Monthly Number of Objects in Earth Orbit by Object Type
Number of Objects
Year
Total
Fragmentation Debris
Spacecraft
Rocket Bodies
Mission-related Debris

Satellite

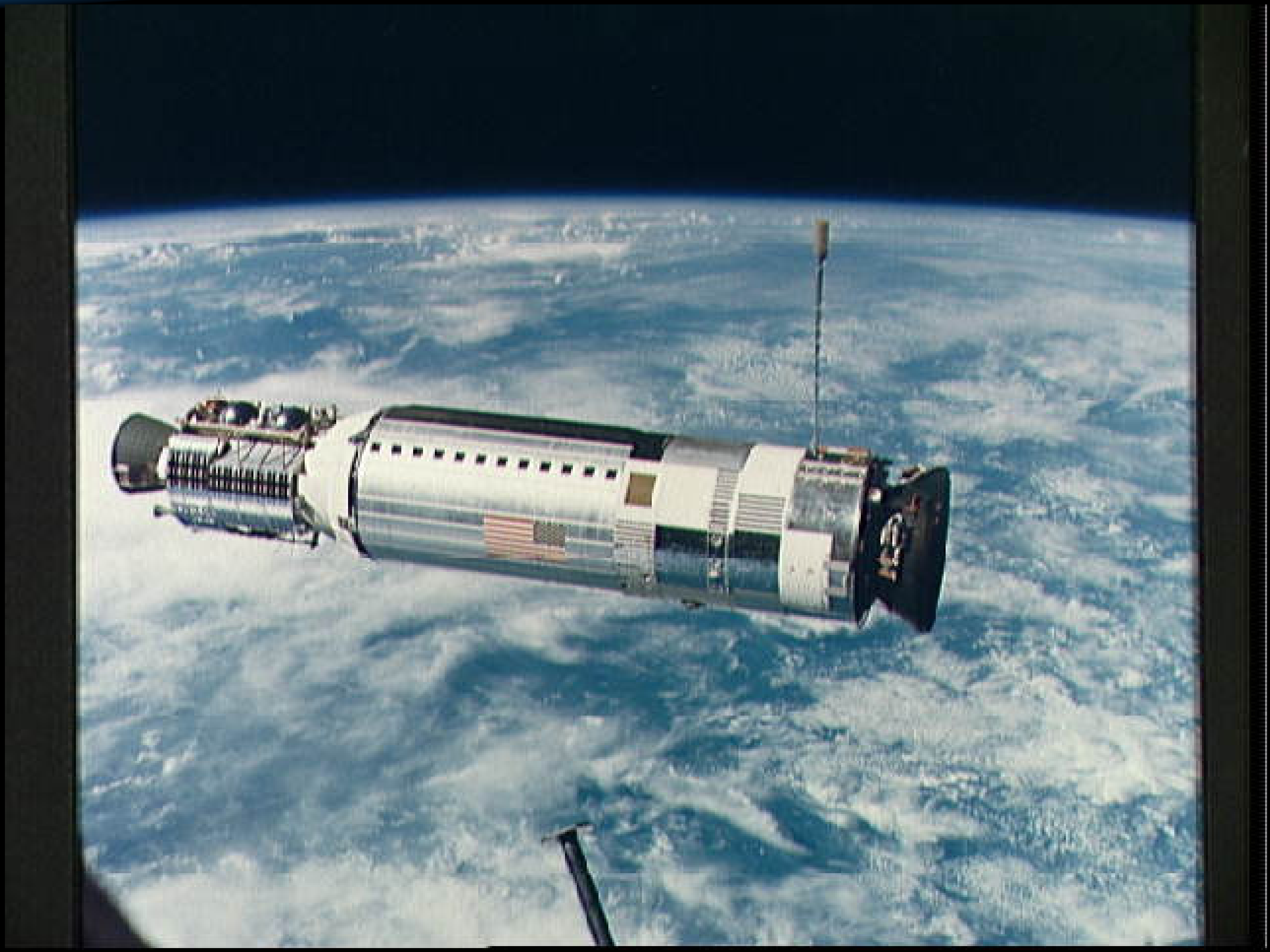
The Strela communications system consisted of a constellation of medium orbit store-dump satellites that provided survivable communications for Soviet military and intelligence forces. The operational constellation consisted of several dozen Strela-1M and 8 Strela-2M satellites. The small Strela-1M was used for open information only, and received data uploads from military units, with the messages held and then retransmitted to ground stations when the satellite was over Soviet territory. The system was developed experimentally in the 1960's, with flight tests from 1964 to 1965. Reshetnev was the chief designer in collaboration with the KB Krasnoyarsk Radio-Technical Factory (V G Taranenko) and MNIIRS MPSS (Yu S Bikov). Flight tests of the operational system began in 1970. Production system work began in 1972. In 1973 the Strela 1M system was accepted by the military. The Kosmos 3M was the launch vehicle, with eight Strela-1M satellites launched at a time. The eight satellites would be in similar 1500 km altitude orbits with periods varying between 114.5 to 116.0 minutes. . The intentional orbital period difference ensured that the satellites would become randomly spaced about the orbital plane shortly after launch. Strela-1M was replaced by the somewhat larger and more capable Strela-3 beginning in 1985. A total of 360 Strela-1M reached orbit before the satellite was phased out in 1992.



Information from astronautix.com

Rocket Bodies

Agena upper stage used as rendezvous target in Gemini program.



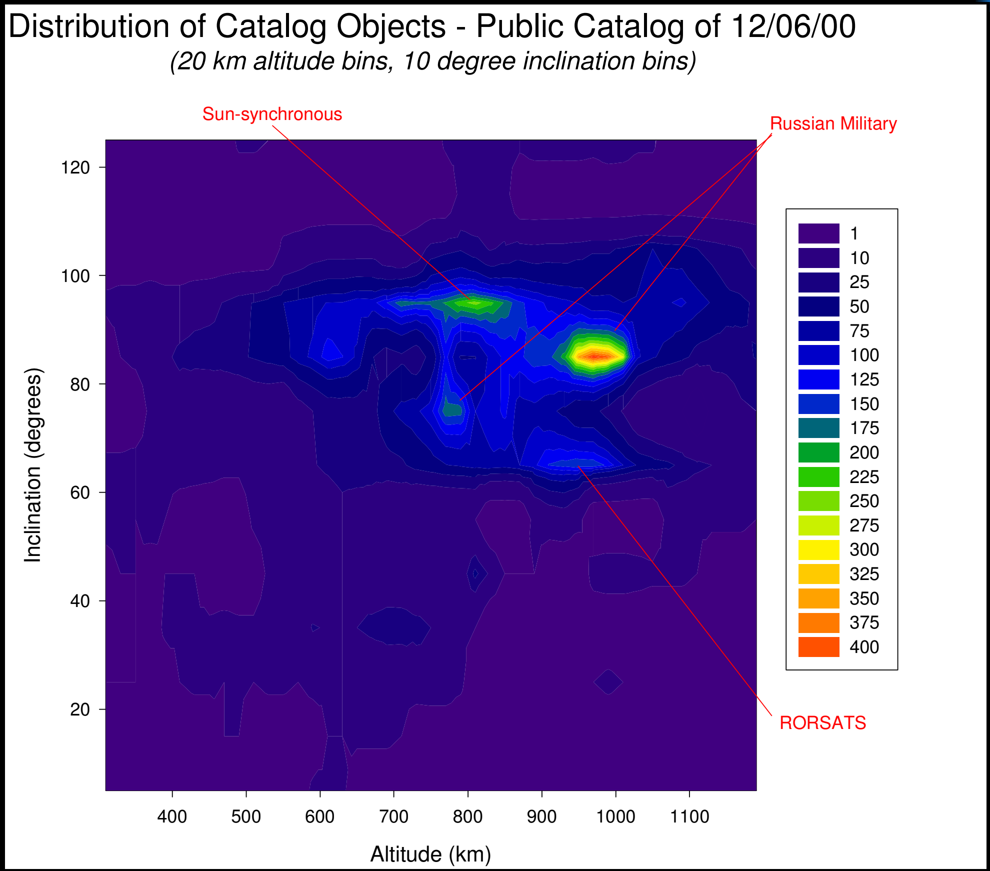
Operational Debris

Payload fairings being shed by a Centaur upper stage on an Atlas rocket.

Astronauts drop things or toss stuff overboard on spacewalks.

Nasty Stuff!

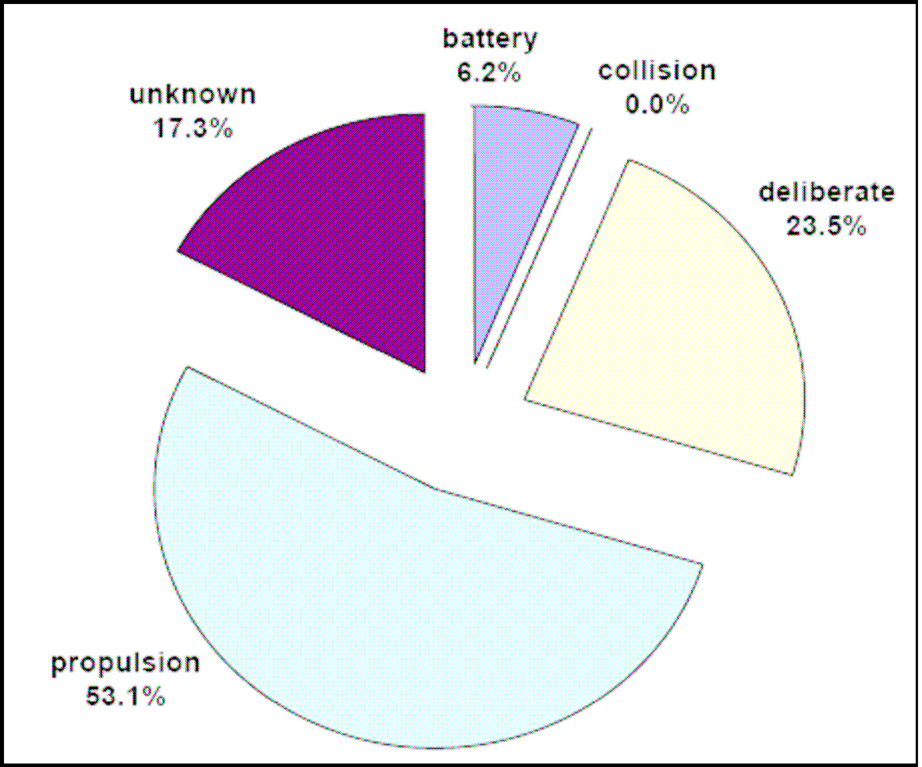
- Soviet Radar Ocean Reconnaissance satellites (RORSATs) were powered by a liquid metal nuclear reactor.
- Launched in the 70's & 80's, these satellites ejected the reactor core into a high orbit at end-of-life.
- However, a "plumbing" problem caused many to leak radioactive drops of liquid sodium into space.



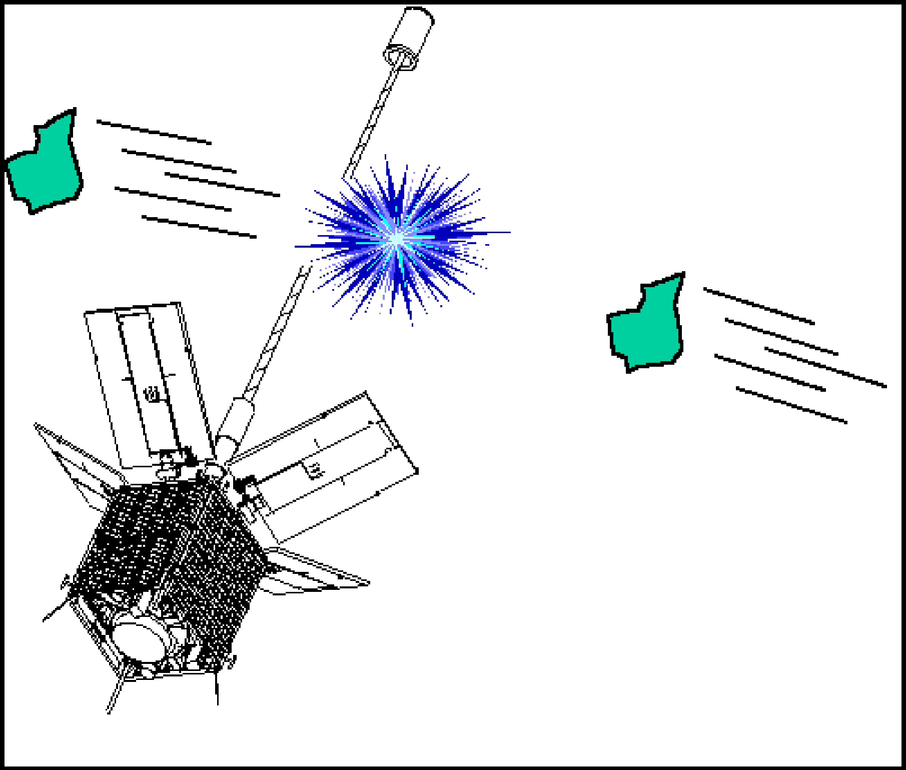
- It is estimated that there are as many as 100,000 of these droplets – some as big as 3 inches – at altitudes between 900 and 1000 km.

Fragmentation Debris

- Produced by explosions, collisions, or deterioration of surfaces.
- Explosions
  - Caused by stored energy, usually residual fuel in upper stages. Pressure will eventually cause tanks to rupture.
  - 10 of these events account for 20% of the catalog.
  - Big problem with older Delta upper stages.



- Collisions
  - Unintentional – debris breaking gravity gradient boom of Cerise satellite in 1996.
  - Intentional – F-15 launched ASAT missile, destroyed SOLWIND P78-1, a gamma ray spectroscopy satellite (1985).

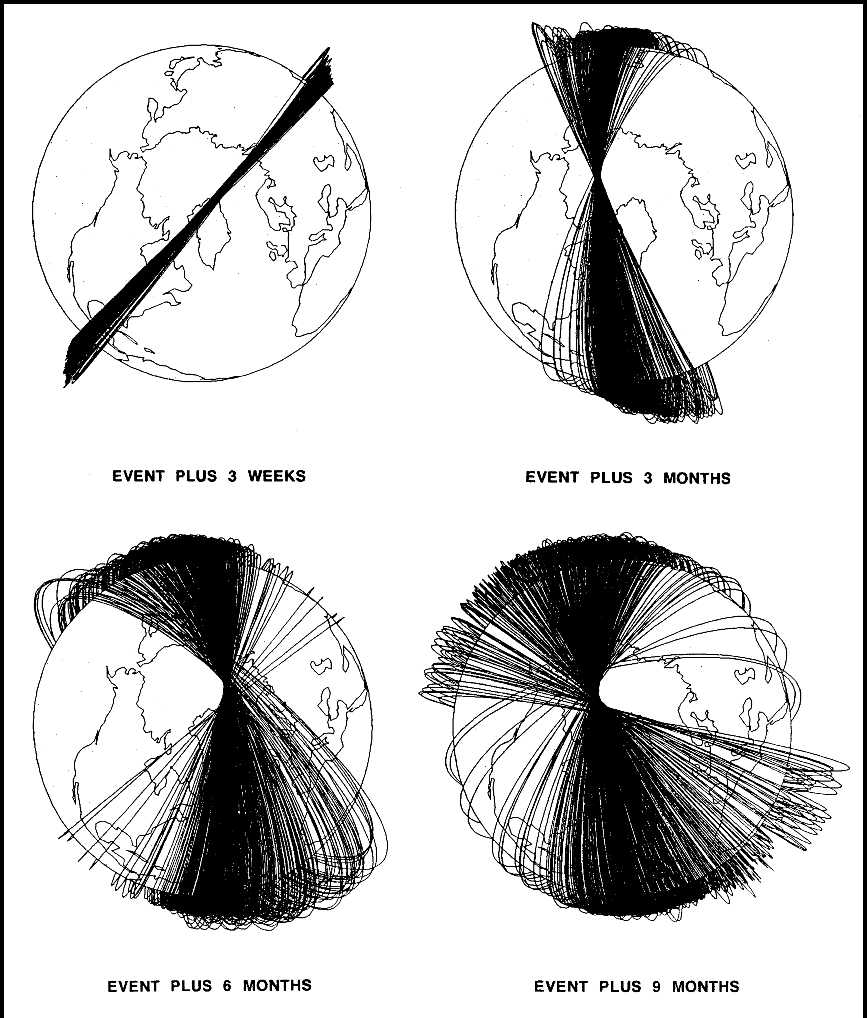


- Deterioration
  - Paint flaking off very common – many craters on exposed surfaces contain paint residue.
  - Can also have bits of thermal blankets, etc.

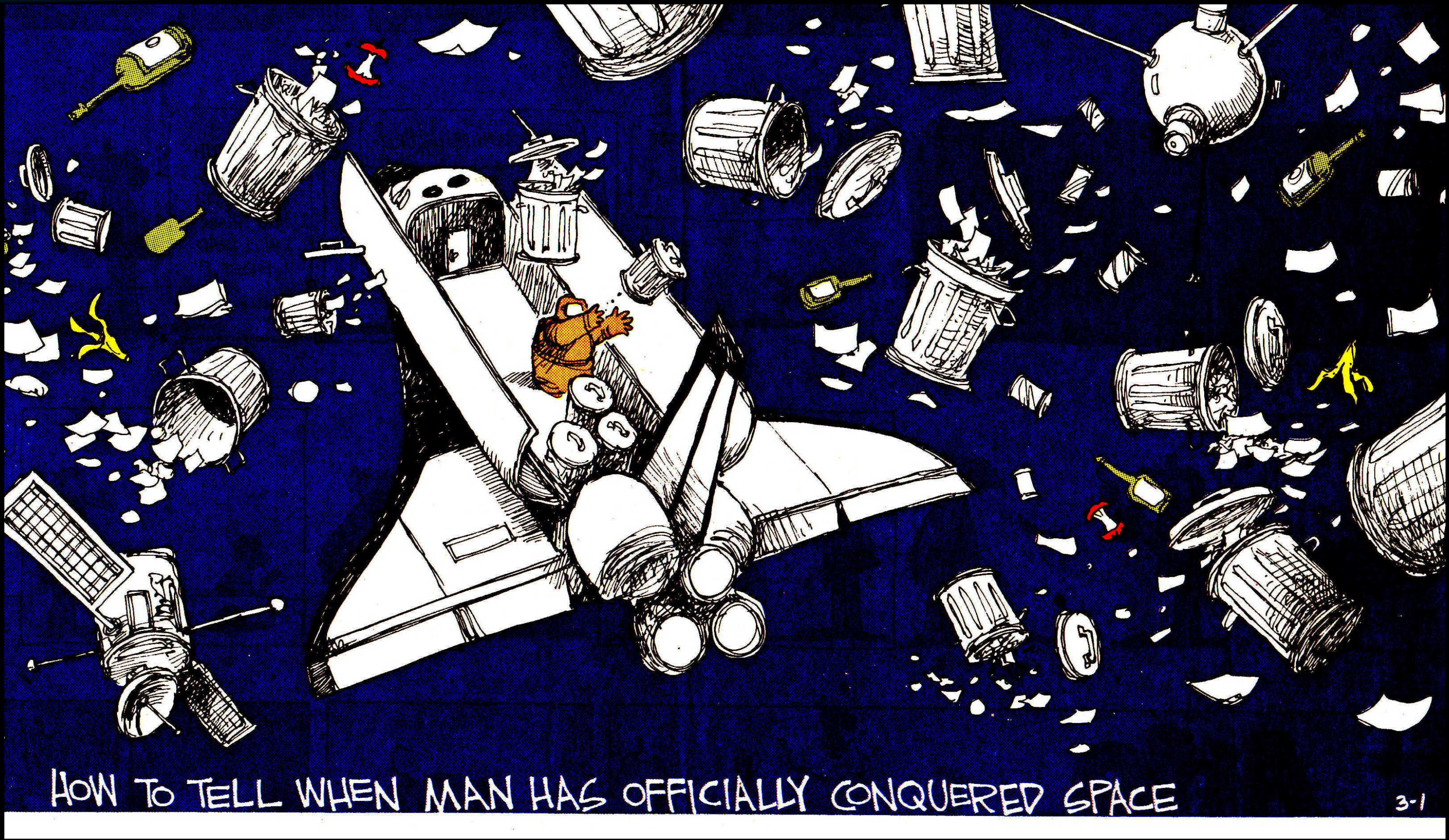
Debris (piece of thermal blanket) coming from Columbia during orbit 3 of STS-107 mission.

Fragmentation of Pegasus Upper Stage

- 3 June 1996 breakup: 2 years after launch and 25 km above Hubble Space Telescope
- Worst recorded event
  - >700 tracked objects
  - >300,000 objects larger than 4 mm
- STS-78 scheduled for 20 June
- STS-82 scheduled to service HST in February 1997
  - Extensive effort to determine risks
- Probable cause of breakup was rupture of propellant tank after failure of regulator let in high pressure helium



Why Should We Care?



The SOCIT Test

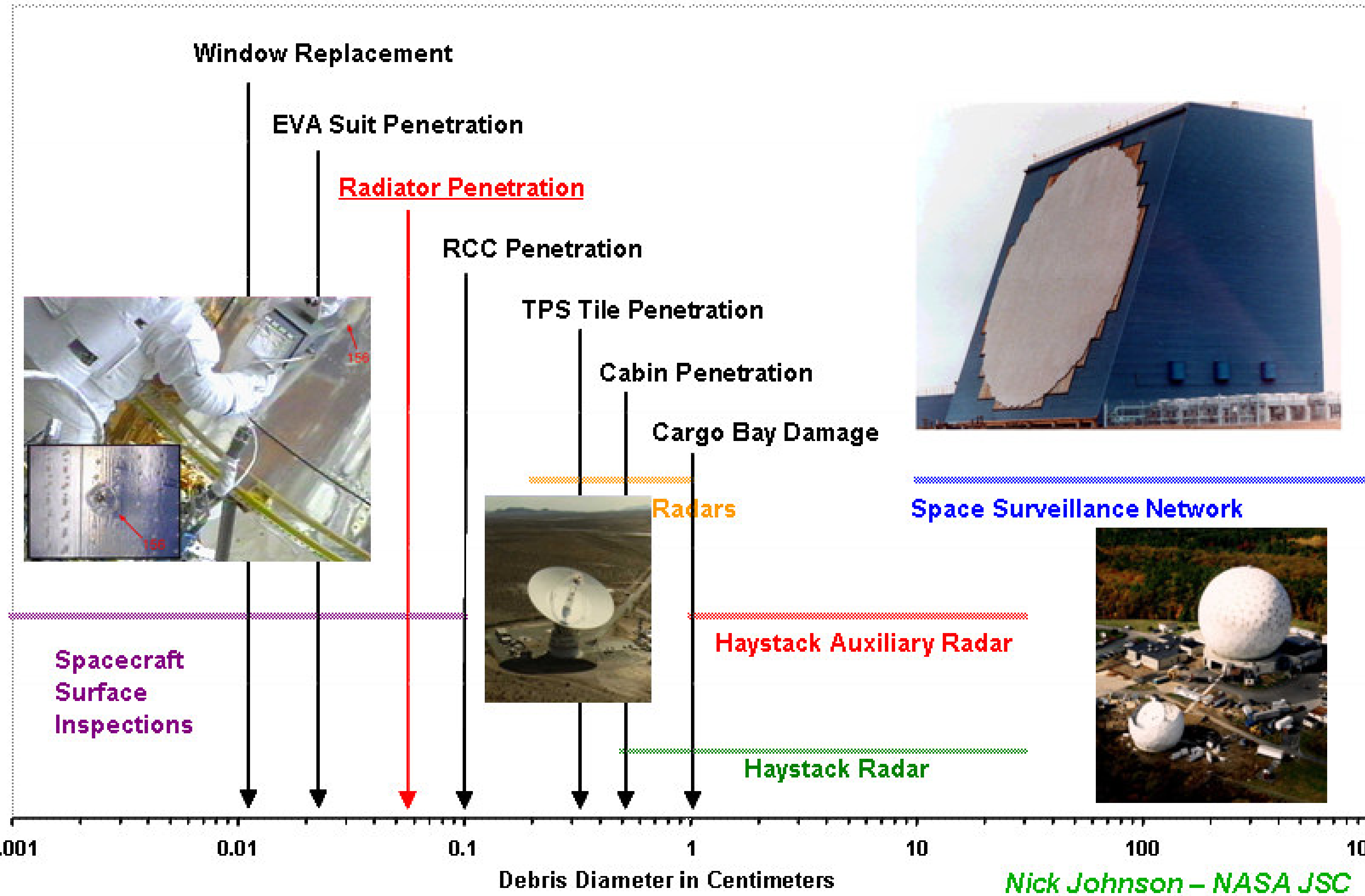
- Ground experiment design to investigate the effects of a hypervelocity impact upon a "typical" spacecraft.
- Satellite chosen was a Navy Transit/OSCAR (navigation/communications).
- A 160 g (4.8 cm) Al sphere was fired into the satellite at 6.1 km s^{-1}.

Before:

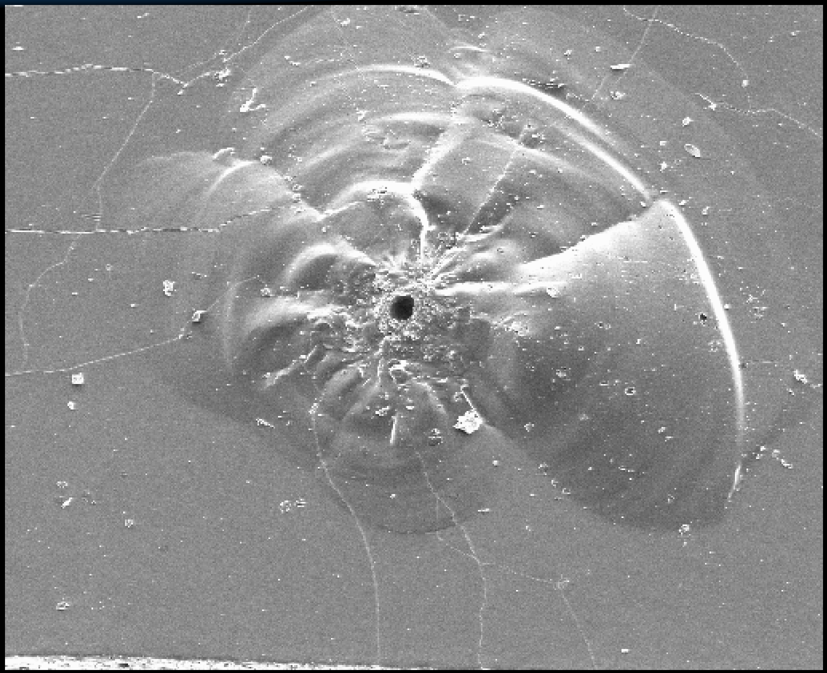
After:

What Can Hurt

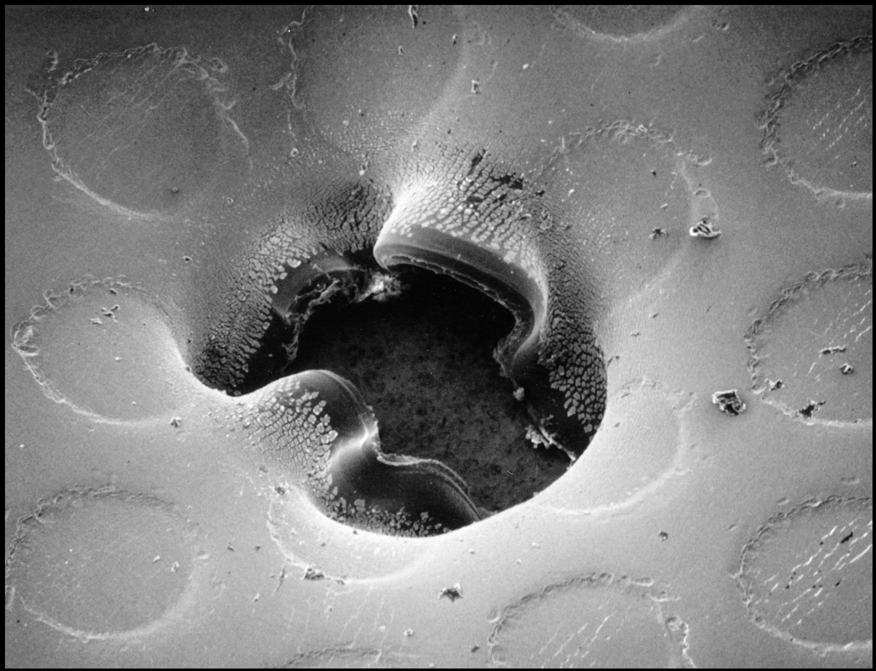
Potential Shuttle Damage



Example Shuttle Impacts



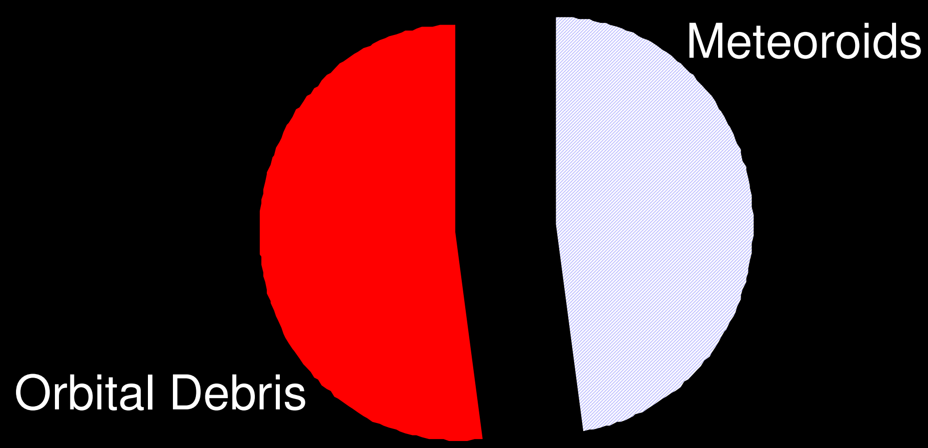
STS-92 Window Impact
~0.1mm Al particle
2 mm diameter crater

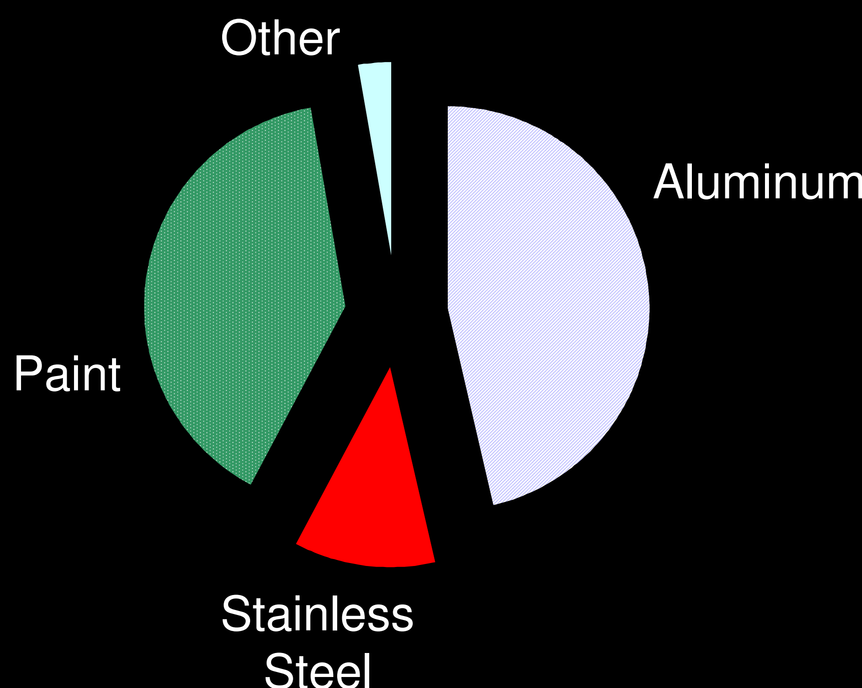


STS-90 radiator penetration
~0.3 mm paint particle
1 mm diameter hole

Types of Shuttle Window Impacts

- **During 1992-2001 a total of 463 Shuttle window impactors were characterized by type**
- **Impactors were typically 0.01-0.06 mm in diameter, but some were as large as 0.2 mm in diameter**





The Sky Does Fall…

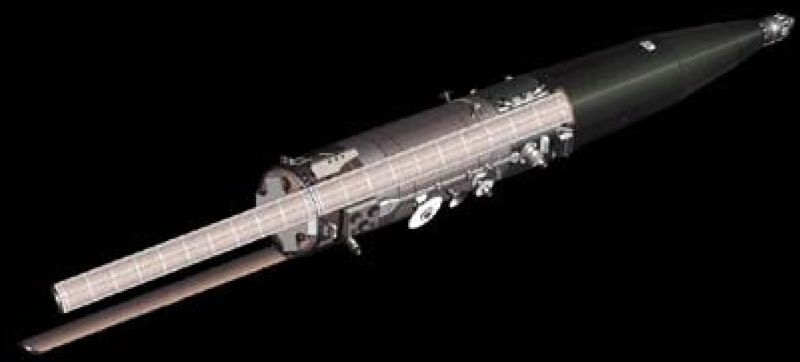
Texas
1997

South Africa
2000

Saudi Arabia
2001

Radioactive Shower

- The reactor core of Cosmos 954, a RORSAT, failed to separate and go into a nuclear-safe orbit at end of mission.
- Satellite reentered on January 24, 1978, crashing near the Great Slave Lake in the Northwest Territory.
- Radioactive fuel scattered over a 48,000 square mile area.
- 12 large pieces recovered, each highly radioactive.



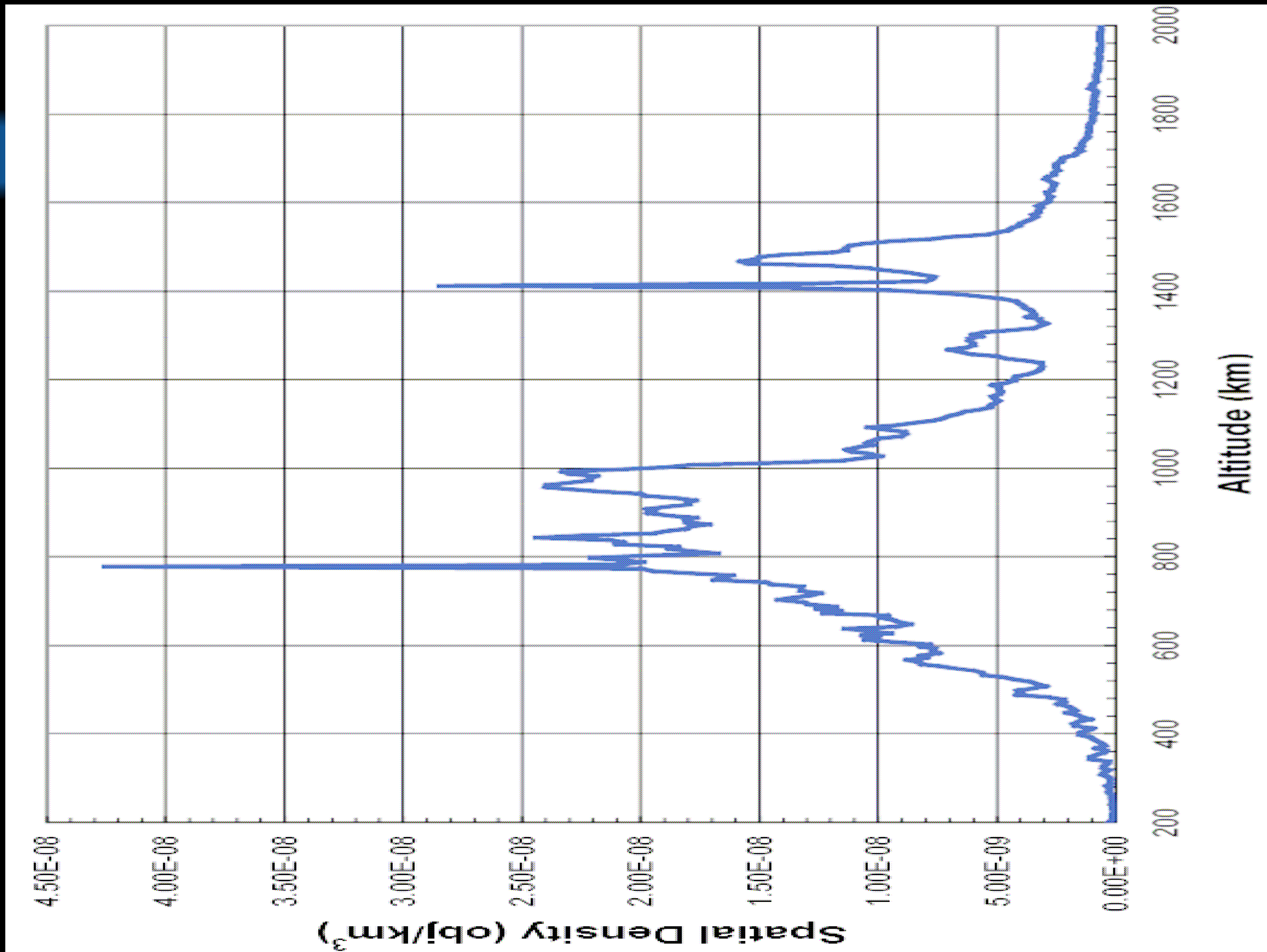
- Canadian government billed the U.S.S.R. 15 million dollars for the recovery effort. Less than half was paid, but the Soviets did acknowledge the satellite was theirs (very unusual).

Ya Break It, Ya Buy It…

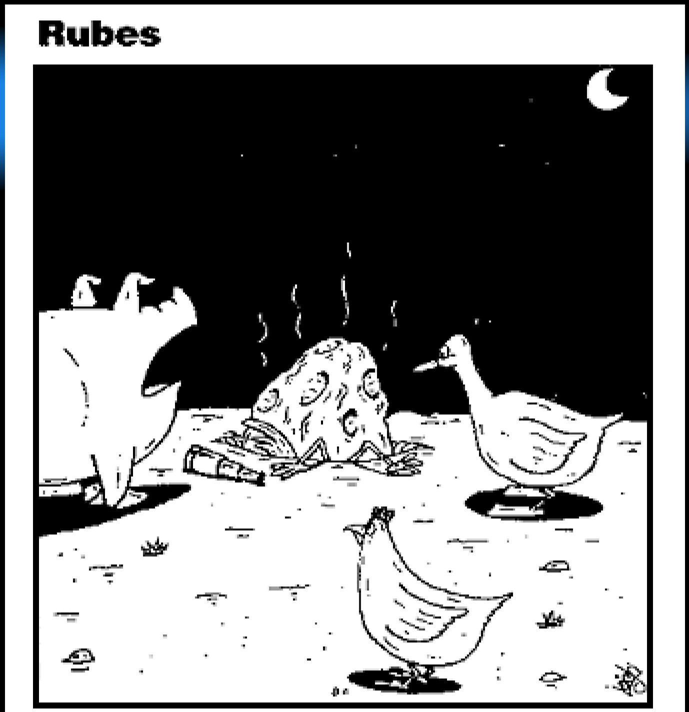
- 1967 Outer Space Treaty and 1972 Liability Convention state that a country or its agencies are liable for damages or loss of life if an active satellite or debris object strikes an object (person) belonging to another nation.
- No incidents – yet (we have come close).

A Nightmare Scenario

- If the number of objects occupying a given altitude (number density) gets too big, a collisional cascade can occur.
- It's sort of like a runaway nuclear reaction – a collision creates debris, which in turn plows into other objects, producing yet more debris, which strike other things. Eventually everything gets pulverized at that altitude, rendering it unusable.
- Some altitudes (~800 km) are rapidly approaching critical.


Spatial Density (obj/km3)
4.50E-08
4.00E-08
3.50E-08
3.00E-08
2.50E-08
2.00E-08
1.50E-08
1.00E-08
5.00E-09
0.00E+00
200
400
600
800
1000
1200
1400
1600
1800
2000
Altitude (km)

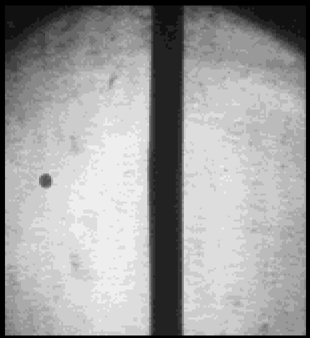
Mitigating the Risk



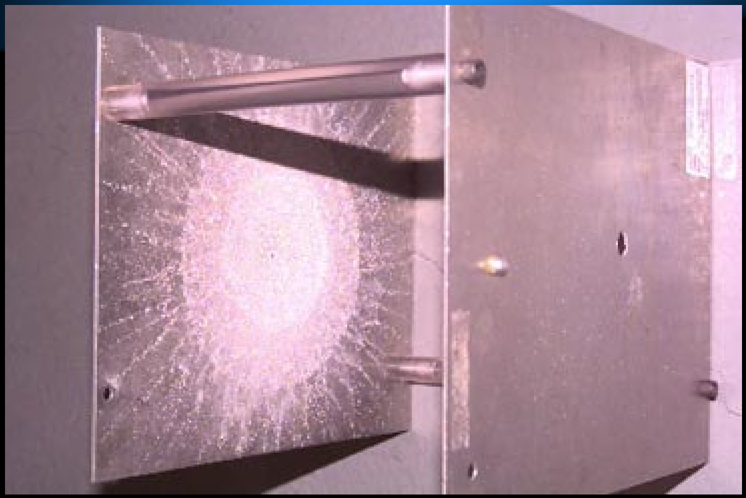
"Well, I'll be ... I guess the little chicken was right."

Shielding

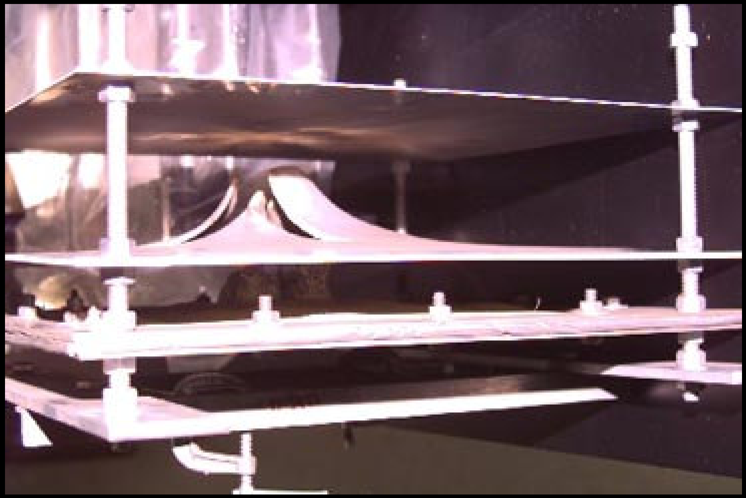
This Monolithic Shield is the brute force approach and does not win any points for ingenuity. It's simply a slab of aluminum capable of absorbing the entire force of an impact. This shielding method is mostly relevant as a comparison to equivalent mass advanced shields. Also, the monolithic shield can be used to represent the "default shielding" (a simple aluminum wall) against meteoroid and debris impacts.



The material on this slide and the next was Taken from the JSC Hypervelocity Impact Test Facility website: http://hitf.jsc.nasa.gov



The Whipple Shield is the first spacecraft shield ever implemented. It was introduced by Fred Whipple back in the 1940s, and is still in use today. Simply, it consists of placing a sacrificial bumper, usually aluminum, in front of the spacecraft, thus allowing it to absorb the initial impact.



The Stuffed Whipple Shield is a variation of the simple Whipple shield. Layers of Nextel and Kevlar are inserted in between the bumper and the rear wall. These additional layers further shock and pulverize the debris cloud such that any fragments reaching the rearwall are benign. Used on ISS.

ISS/Shuttle Collision Avoidance

- NASA contractor at SPACECOM uses workstation to process catalog information for the purpose of predicting close approaches to ISS several days into the future.
- Object projected to pass close to station gets enhanced observation by tracking sites and more elaborate propagation scheme.

- Position error ellipsoids are computed for both vehicle and the object – the degree to which these ellipsoids intersect determines probability of collision.
- If probability is above red level (1 in 10,000), vehicle must maneuver. If above yellow level (1 in 100,000), maneuver at project’s discretion.
- ISS has made 7 maneuvers, Shuttle 2.

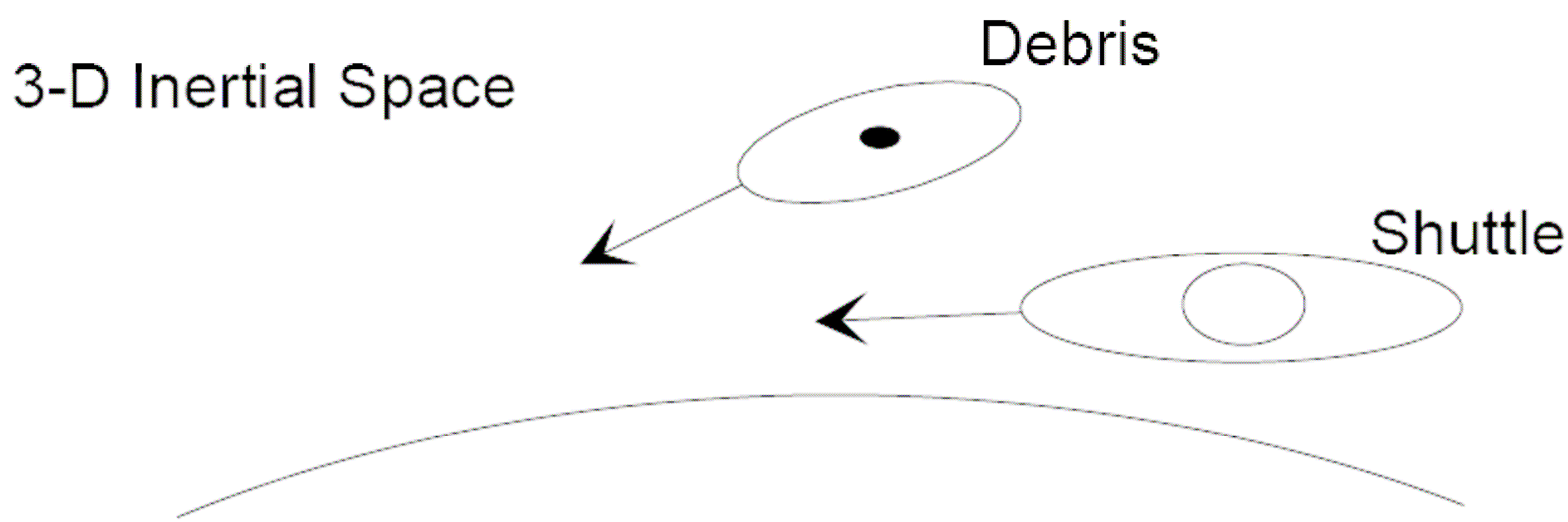
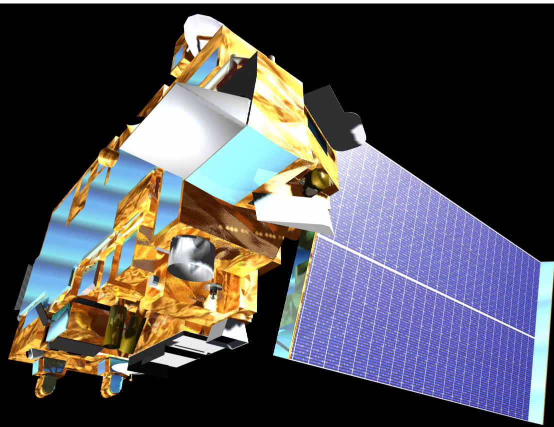


Fig. 3.1: Depiction of Conjunction Scenario

From "Probability-based Space Shuttle Collision Avoidance", D. Leleux et al, Space Ops 2002 Conference



The Terra Conjunction

- A close approach between Terra and object 14222 was initially identified on Monday, October 17th with a time of closest approach of Time of Closest Approach: 23-Oct-2005 20:53:28 UT.
- Object 14222 is debris from a Scout vehicle.

Scout debris orbit:
Period: 98.66 min
Apogee Height: ~ 710.79 km
Perigee Height: ~ 679.20 km
Inclination: ~ 82.39 degrees

Terra orbit:
Period: 98.57 min
Apogee Height: ~ 712.03 km
Perigee Height: ~ 704.24 km
Inclination: ~ 98.20 degrees

- The miss distance was predicted using different orbit solutions for Terra from both Goddard and Cheyenne Mountain (Cheyenne Mountain-only solution for 14222):
  - Cheyenne Mountain Solution #1: 413 meters
  - Cheyenne Mountain Solution #2: 114 meters
  - Goddard Solution #1: 297 meters
- Collision probability of 1 in 100 (0.01).
- The conjunction was reported to occur above a latitude of 80.01° N and a longitude of 258.28° E with a relative velocity of 11.86 km s^{-1}.
- Terra maneuvered on Friday, October 22, at 22:30 to avoid the possible collision.

U.S. Space Policy and Orbital Debris

- **Orbital debris has been included in all national space policies since 1988.**
- **Current National Space Policy (PDD-NSC-49/NSTC-8, 14 Sep 1996) expanded orbital debris description:**

"The United States will seek to minimize the creation of space debris. NASA, the intelligence Community, and the DoD, in cooperation with the private sector, will develop design guidelines for future government procurements of spacecraft, launch vehicles, and services. The design and operation of space tests, experiments and systems, will minimize or reduce the accumulation of space debris consistent with mission requirements and cost effectiveness.

"It is in the interest of the U.S. Government to ensure that space debris minimization practices are applied by other spacefaring nations and international fora to adopt policies and practices aimed at debris minimization and will cooperate internationally in the exchange of information on debris research and the identification of debris mitigation options."

U.S. Government Orbital Debris Mitigation Standard Practices

- In response to 1995 Interagency report, NASA and DoD developed draft orbital debris mitigation standard practices based upon NASA Safety Standard 1740.14.
- Standard Practices cover four major areas:
  - **Control of debris released during normal operations**
  - **Minimization of debris generated by accidental explosions**
  - **Selection of safe flight profile and operational configuration**
  - **Postmission disposal of space structure**
- Standard Practices are being used as foundation for development of international guidelines.

Mitigation Commandments

I. Thou shalt passivate thy upper stages (get rid of stored energy – vent fuel, safe batteries, etc.).
II. If in LEO, thou shalt remove thy satellite's carcass within 25 years from thy mission end.
III. If in GEO, thou shalt park thy dead satellite no closer than 200 km to the GEO belt.
IV. Being merciful, thy satellite and its operational debris shalt have less than 1 in a million chance of colliding with any other active satellite.
V. The flaming wreckage of thy satellite shalt not have a chance greater than 1 in 10,000 of bonking a ground-dweller on his head.

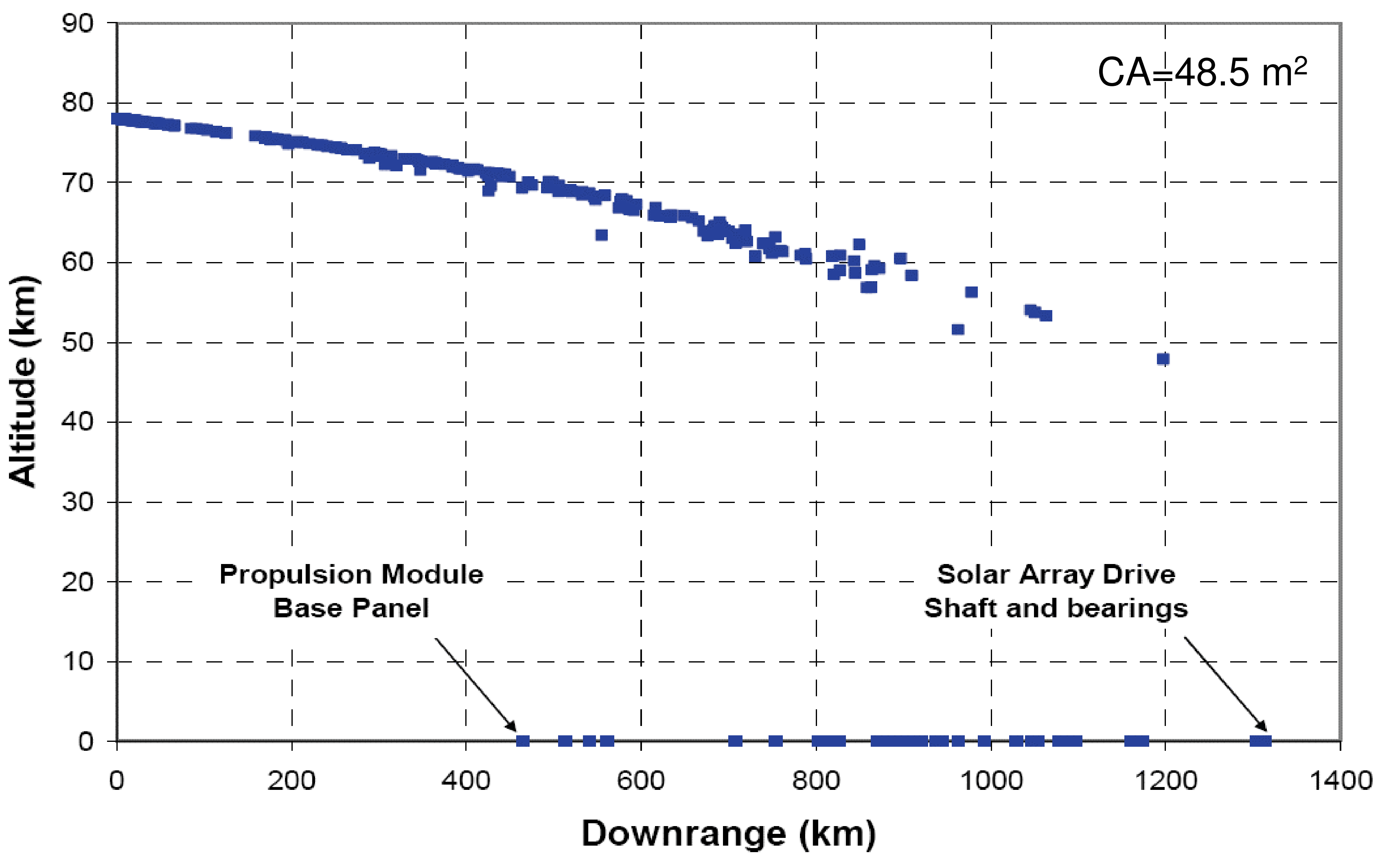
Ramifications

- All NASA missions (unless launched before 1995) must comply with the preceding.
  - Software is available to help mission designers/planners insure compliance (http://www.orbitaldebris.jsc.nasa.gov/mitigate/das.html).
- Major consequence is that some missions must carry additional fuel to de-orbit within 25 years (drag will not do it for you at sun sync altitudes) or do a controlled re-entry.
  - Less room for instrumentation.
  - Can impact possible extended mission.
  - De-orbit/parking operations induce additional (often small) costs).

What Makes It to the Ground?

- DAS software gives a rough idea – NASA's ORSAT program is used for detailed reentry risk assessments.
  - Calculates debris field and "casualty area."
  - Only surviving debris with kinetic energy greater than 15 joules counted.
- If risk to population exceeds 1 in 10,000 threshold, satellite must perform a controlled reentry into an ocean.
- Risk assessment required before launch; should be done in design phase.

Terra ORSAT Analysis



The practices are working!